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Mitigating Plant and Soil Health Options through Climate Resilient Maize-Mungbean Based Intercropping for Rainfed Agriculture

Nasir Mehmood Khan [a*], Ghulam Mujtaba [a], Adeel Anwar [a], Fahad Ali Fayyaz [a], Muhammad Ryan Ahmad Khan [a], Muhammad Faheem Khan [a], Muhammad Amaid Khan [b], Muhammad Aashir Bilal Khan [a] and Muslim [c]

[a] Department of Agronomy, Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi, Pakistan.
[b] Department of Agronomy, University of Haripur, Haripur, Pakistan.
[c] Directorate of Agriculture Research (Dates), Kech, Turbat, Balochistan, Pakistan.

Authors' contributions

This work was carried out in collaboration between all authors. Author NMK designed the study, performed major soil and plant analysis along with writing the first draft of the manuscript. Authors GM and AA helped in arranging field experiment, managed data analysis and proofread the final draft. All authors read and approved the final manuscript.

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ABSTRACT

An experiment was conducted at National Agricultural Research Council (NARC), Islamabad to evaluate the response of intercropping in maize and mungbean with implementation of vermicompost (VMC) and chemical fertilizer (CF). The experiment was laid down in RCBD with split plot arrangement having three replications. The main treatments were cropping practices; sole

**Corresponding author: E-mail: nasirniazi336@gmail.com;*

maize (SM), sole mungbean (SM) and intercropped maize mungbean (M-Mb) though sub treatments included nutrient management practices; vermicompost (VMC) and chemical fertilizer (Urea + DAP) (CF). The data was recorded for plant parameters of chlorophyll content (mg/g), rate of photosynthesis (µmol/s), intercellular CO_2 (ppm), protein content (%) and grain yield (kg/ha) while soil parameters that were estimated included are; soil pH, electric conductivity (dS/m), cation exchange capacity (cmol/kg), exchangeable Ca (cmol/kg), exchangeable Mg (cmol/kg), soil organic matter content (%), available N (ppm), available P (ppm), available K (ppm). The analysis of the data revealed that all of the studied traits were significantly affected by the intercropping. The increased value of chlorophyll content (67.12 and 61.07 mg/g) was obtained in intercropped maize-mungbean (M-Mb) with vermicompost (VMC) treatment, maximum rate of photosynthesis (25.33 and 20.76 µmol/s) was obtained by maize and mungbean in maize-mungbean (M-Mb) intercropping along with vermicompost (VMC) treatments. Correspondingly, protein content (28.15 and 16.43 %) and grain yield (9246.1 and 1610.71 kg/ha) for maize and mungbean were improved by the application of maize-mungbean (M-Mb) and vermicompost (VMC) treatments. There was also increase in the values of soil pH EC (6.44), CEC (44.31 cmol/kg), exchangeable Ca (6.42 cmol/kg), exchangeable Mg (2.21 cmol/kg), SOM content (0.78%), available N (2.98 ppm), available P 18.67 ppm) and available K 198.76 ppm) with the implementation of vermicompost and maize-mungbean intercropping treatments. Overall, the study revealed that intercropping is a best way of increasing crop yield and quality along with the amendment of vermicompost, also bringing positive changes in the soil properties and health.

Keywords: Maize; mungbean; intercropping; soil health; plant health; vermicompost; chemical fertilizer; grain yield and organic matter.

1. INTRODUCTION

Intercropping is "the technique of planting two or more crops on the same plot of land in the same year to foster interaction and increase production by avoiding reliance on a single crop" [1]. Many tropical agricultural systems rely on various intercropping arrangements for legumes and non-legumes [2,3]. Intercropping is most typically used on small-scale farms with limited space, necessitating the growth of many plants on the same plot of agricultural land at one time. Reduced rainfall and/or unpredictable distribution of rainfall may drive farmers to intercrop in order to maximize water use, but this could end in competition for scarce resources in the extreme [4]. The primary advantages of intercropping are decreased failure of growth risk and agricultural diversification, nutritive crops are typically intercropped with commercial crops to help offer both nourishment and additional money [5]. The intercrop is more efficient at utilizing resources such as light, water, and nutrients [6].

Increasing plant variety, in an intercrop setting, is also recommended as a way to increase robust and sustainable agricultural methods [7]. One element that drives production variations between mixes and pure crops is competing for soil obtainable sunlight, nutrients, and water [8]. Multiple standards are employed to assess the prospective benefits of intercropping and interactions between species. Their choices, usage, and significance are critical for interpreting scientific information as well as enabling us to evaluate results from other studies [9].

Globally, maize (*Zea mays*), a primary cereal food, is extensively farmed. Due to a roughage scarcity, substantial emphasis has been dedicated to its feeding value in recent years. Maize can produce massive amounts of energy-rich forage for animal diets, and its fodder may be fed safely at all phases of growth without the risk of oxalic acid or prussic acid toxicity that sorghum does [10]. But its greatest disadvantage is its minimum crude protein content, ranging normally between 70 and 80 g/kg dry matter (DM) [11].

Mungbean (*Vigna radiata*) is an herbaceous annual crop produced mostly in the tropics' dry agro-ecologies in Latin America, Africa, and South Asia [12]. It is a legume of the Fabaceae family, tribe Phaseoleae, genus Vigna, and section Catiang. Maize belongs to the poaceae family and is a grain crop, whereas mungbean belongs to the fabaceae family and is produced for its edible legumes. As a result, intercropping cereals and legumes helps to preserve soil fertility. Legumes assist to fix atmospheric nitrogen, which might benefit the host plant or be utilized by another nearby plant [13]. Mungbean (*Vigna radiata*), an annual legume with high levels of protein (about twice that of maize), can be combined with maize to increase the protein content of diets and, as a consequence, reduce the cost of producing high-quality feed [14]. Several studies have also revealed that intercropping mungbean and maize increased biomass production (20-40%) [15] and protein (11-15%) [16].

2. MATERIALS AND METHODS

2.1 Experimental Site and Material Collection

Maize and mungbean varieties were evaluated for different yield and quality related parameters along with soil attributes through intercropping at National Agricultural Research Center (NARC), Islamabad, Pakistan. The experimental material was provided by Fodder and Forage Research Program, Crop Sciences Institute, NARC Islamabad.

2.2 Crops Plantation

The seeds were sown in randomized full blocks with split plot arrangement with three replications. The main treatments included the 3 cropping practices (CP), sole maize (SM), sole mungbean (SMb), intercropped maize mungbean (M-Mb) while sub treatments that were used are 2 nutrient management practices (NMP), vermicompost (VMC) and chemical fertilizer (Urea + DAP) (CF). Every replication had been produced in a plot containing four rows where length of row was kept at 3 meters along with 6m × 3 m plot size. Row to row spacing of 75 cm were kept for sole maize and mungbean whereas intercropped treatment had row to row distance of 100 cm.

Experimental Set-up:

Plot Size: 6m × 3m = 18 m^2

Design: RCBD with split plot arrangement
Replications: 3

Number of Rows: 4

Row Spacing: 75 cm for both maize and mungbean, 100 cm for intercropped treatments.

2.3 Crop Husbandry

The experimental area received 10 cm of pre-soaking irrigation during the season. For the preparation of seedbed, soil had to achieve field capacity. Table 1 shows the crops that were grown according to the suggested production technology for the area. With a hand drill, all the crops were manually seeded in lines. The first irrigation was given after germination of crops and second irrigation was given after 15 days of germination whereas remaining irrigation was provided after 20 days of previous irrigation. Urea and DAP (nitrogen-based fertilizers) were used as chemical fertilizer treatment (CF), DAP was applied with sowing while 1/3rd portion of urea was applied at sowing time. The rest of the urea fertilizer was applied during the second and third irrigation, respectively. Vermicompost (VMC) was applied and intermixed properly in soil before sowing. In the cropping season, diseases, insects, and pests were managed by implementing the necessary agronomic and crop protection methods. The plant and soil samples from every plot of both crops were estimated after the harvest of maize and mungbean.

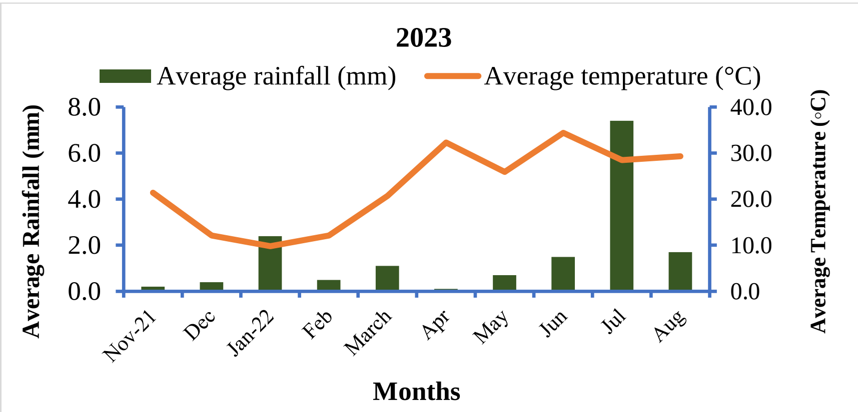


Fig. 1. Average temperature and rainfall in the experimental site (NARC, Islamabad) in 2023. (Source: Climate Observatory at NARC, 250 m away from experimental location)

Table 1. Details of crops sown to estimate the effect of intercropping and nutrient management practices on plant and soil growth

Crops	Sowing Time	Varieties	Seed Rate (kg/ha)	P-P (cm)	R-R (cm)	Harvesting Time	Harvest Method
Maize	24 March	DS-2003	35	15	75	08 September	Manual
Mungbean	24 March	NM-2011	75	10	30	08 September	Manual

2.4 Plant Parameters

Chlorophyll is an important photosynthetic pigment for the plant, which helps in determining the photosynthetic capacity as well as plant growth so it is very important to measure chlorophyll content of plant. Leaf chlorophyll content was reliably determined by extracting chlorophyll in a solvent and then measuring it in vitro with a spectrophotometer. Non-destructive, in-situ optical approaches, on the other hand, have become frequently employed to offer a relative estimate of leaf chlorophyll content. The concentration of chlorophyll in plant leaves is commonly represented in terms of amount per area of leaf surface, micromoles per square meter (mg/g), or mass per area of leaf surface, milligrams per square meter (mg/m^2). Photosynthetic rate was measured with the help of infrared gas analyzer CI-340 handheld photosynthesis system (IRGA). CO_2 uptake was evaluated using an IRGA (Infrared-Red Gas Analyzer), which can compare the amount of carbon dioxide (CO_2) in gas entering into a chamber around a leaf per plant to the CO_2 concentration exiting the chamber. Plant specimen protein concentration was assessed using Kjeldahl technique and traditional nitrogen to protein (N:P) transformation value 6.25, as well as the sum of residues of amino acids. The grain yield was measured by estimating the weight of samples taken from 1 m^2 area through quadrant and then the resulted value was multiplied with 10000 to figure out the amount from 1 hectare.

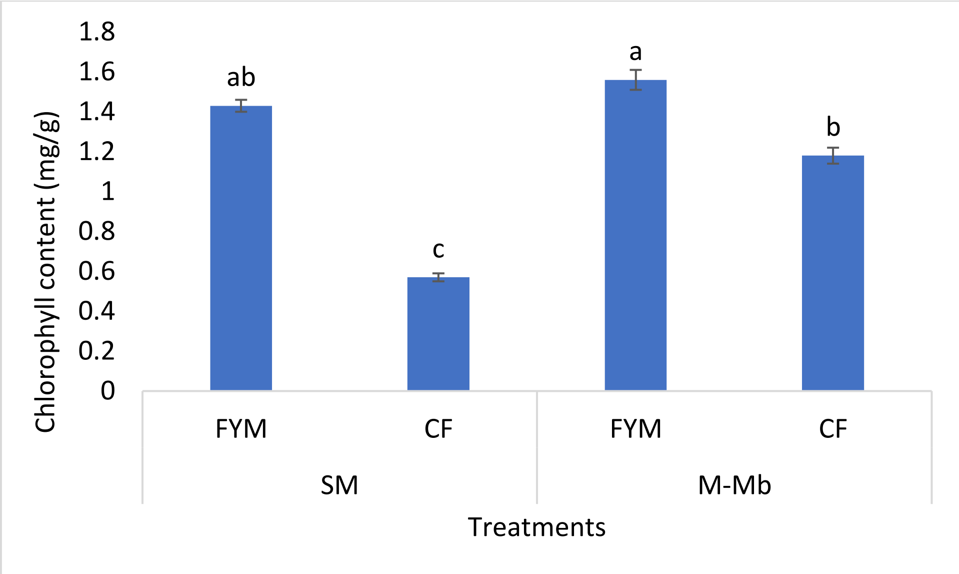
2.5 Soil Parameters

Composite soil samples (0–15 cm depth) were obtained from each experimental unit for post-harvest soil analysis of pH. electric conductivity (EC), cation exchange capacity (CEC), exchangeable Ca, exchangeable Mg, soil organic content (SOM), available nitrogen, available phosphorus and available potassium. To find out the value of soil organic matter content we will multiply organic carbon (OC) by 1.73 while Walkley and Black method was followed to determine OC titrimetrically. To find out the value of available phosphorus soil was shaken with 0.03 M NH_4F—0.025 M HCl solution at pH < 7.0. To find out the exchangeable calcium (Ca) and magnesium (Mg) contents we have used acetate extracted method and then ethylene-di-amine tetra acetic was applied to find value of Ca and Mg. Glass electrode pH meter was used to measure the pH value. CEC was calculated by mean of NH_4OH extraction method. Available nitrogen was determined by Kjeldahl method. To evaluate the value of available K was determined by using the ammonium bicarbonate-DTPA technique (AB-DTPA).

3. RESULTS

3.1 Plant Parameters

Chlorophyll is a vital photosynthetic pigment in plants, influencing photosynthetic capability and hence plant development. A significant variation was noticed for chlorophyll content (mg/g) as a result of nutrient treatments on both maize and mungbean (Fig. 2a & Fig. 2b). The means for various treatments for maize ranged from 0.57 to 1.56 mg/g (Fig. 2a). Maize genotype under intercropped treatment maize-mungbean (M-Mb) had maximum chlorophyll content (1.56 mg/g) while minimum chlorophyll content (0.57 mg/g) was obtained in sole treatment (SM). It is also observed that the vermicompost (VMC) is suitable for obtaining increased chlorophyll content in maize-mungbean (M-Mb) intercropping. On the other hand, the means for various treatments for mungbean ranged from 28.07 to 13.87 mg/g (Fig. 2b). Mungbean has observed better chlorophyll content of 28.07 mg/g in intercropped treatment with addition of vermicompost (VMC) though diminished value of chlorophyll content (13.87 mg/g) was shown by sole mungbean (SMb) with application chemical fertilizer (CF). It shows that the intercropped maize-mungbean (M-Mb) with vermicompost (VMC) is suitable for maximizing the chlorophyll content.



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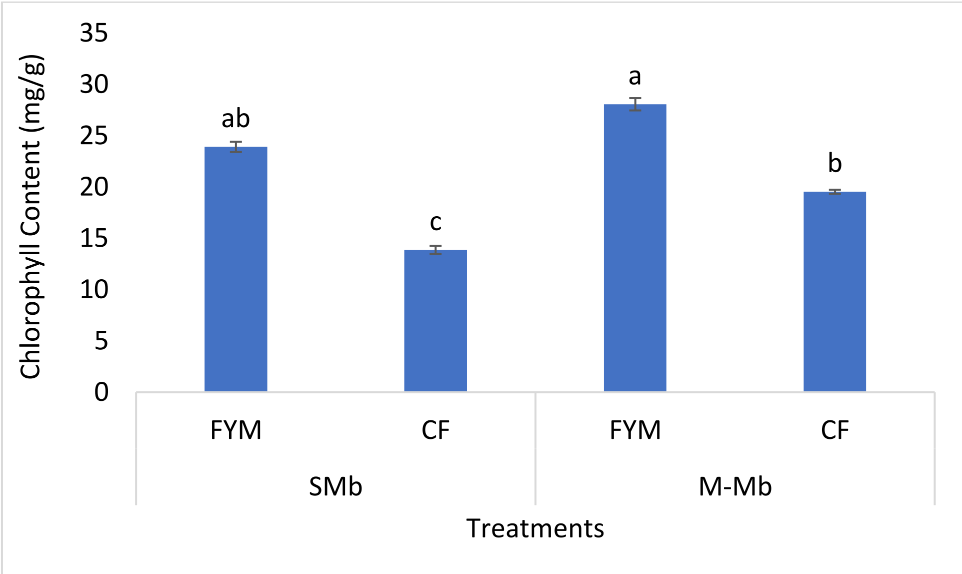
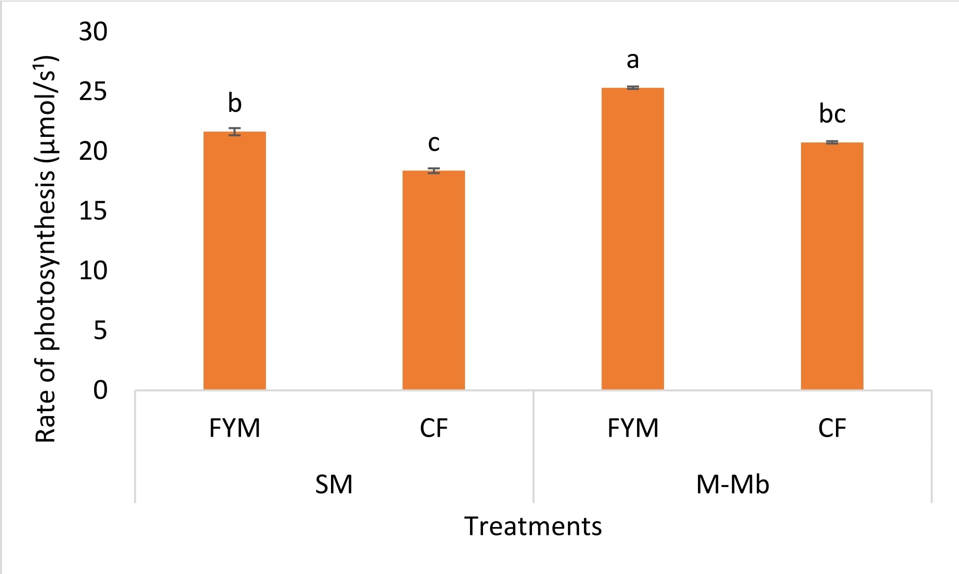


b

Fig. 2a & 2b. Effect of different cropping practices and nutrient management practices on chlorophyll content (mg/g) of maize and mungbean, respectively

The rate of photosynthesis influences agricultural crop productivity. It guarantees that all living things in the atmosphere have access to oxygen. It regulates the quantities of oxygen and carbon dioxide in the ecosystem. A significant variation was noticed for photosynthesis rate (µmol/s) as a result of different nutrient treatments and cropping practices on both maize and mungbean (Fig. 3a & Fig. 3b). The means for various treatments for maize ranged from 18.38 to 25.33 µmol/s (Fig. 3a). The rate of photosynthesis improved (25.33 µmol/s) which is followed by sole maize (SM) treatment with vermicompost (VMC) having photosynthetic rate of 21.65 µmol/s whereas photosynthesis rate (18.38 µmol/s) was observed lowest in sole maize (SM) treatment with application of chemical fertilizer (CF). Conversely, the means for various treatments for mungbean ranged from 14.24 to 20.76 µmol/s (Fig. 3b). Mungbean genotype under vermicompost (VMC) treatment with intercropped maize-mungbean (M-Mb) exhibited



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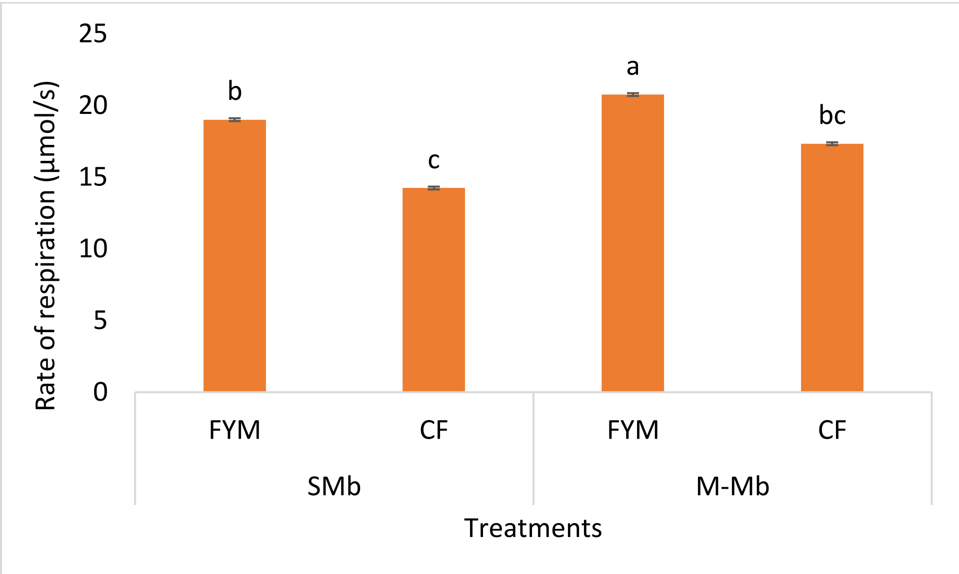
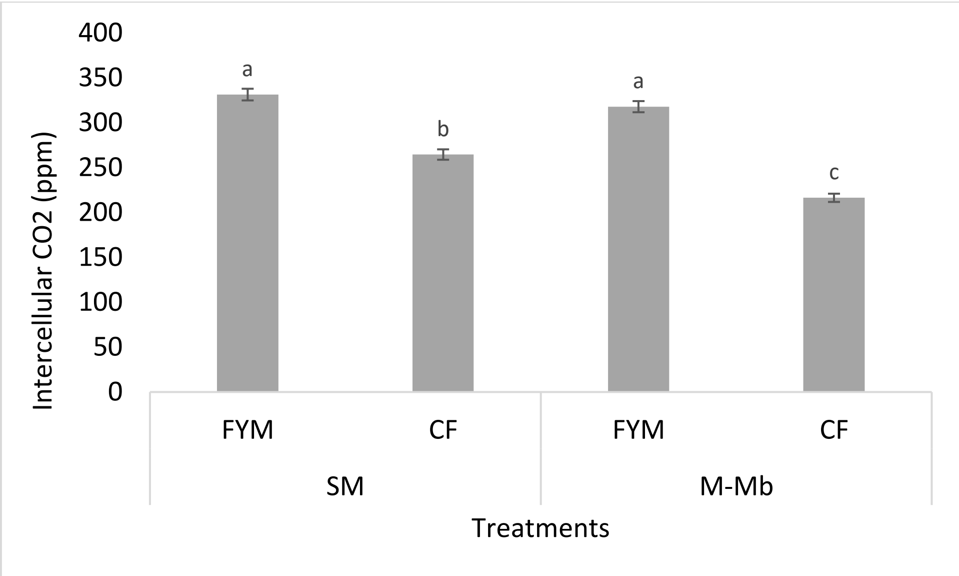


b

Fig. 3a & 3b. Effect of different cropping practices and nutrient management practices on rate of photosynthesis (µmol/s) of maize and mungbean, respectively

maximum photosynthesis rate (20.76 µmol/s) while least photosynthesis rate (14.24 µmol/s) was present in chemical fertilizer treatment in sole mungbean (SMb) followed by intercropping maize-mungbean (17.33 µmol/s). It is illustrated that the intercropped treatment of maize-mungbean with vermicompost (VMC) is appropriate for obtaining minimizing rate of photosynthesis.

If stomatal apertures and external concentration stay constant throughout photosynthesis, the concentration of carbon dioxide in a leaf's intercellular spaces dictates the flow of carbon dioxide into the leaf. In the present experiment mean square values for intercellular CO_2 (ppm) showed significant variations in both maize and mungbean under the effect of cropping and nutrient management practices. The means for various treatments for cropping practices ranged from 216.35 to 331.36 ppm (Fig. 4a & 4b). Sole cropping of maize (SM) with amendment of vermicopost (VMC) had given maximum intercellular CO_2 value (331.36 ppm) for maize while minimum intercellular CO_2 (216.35 ppm) was obtained for maize in intercropped maize-mungbean (M-Mb) treatment with accumulation of chemical fertilizer (CF). Apart from this, the means for various treatments for mungbean ranged from 123.29 to 238.86 ppm (Fig. 4a). Increase in the value of intercellular CO_2 for mungbean was observed in sole mungbean (SMb) with treatment of vermicompost (VMC) (238.86 ppm) followed by intercropped maize-mungbean (M-Mb) (198.77 ppm) despite this, minimum intercellular CO_2 (113.75 ppm) was experienced in maize-mungbean (M-Mb) and chemical fertilizer (CF) treatment.



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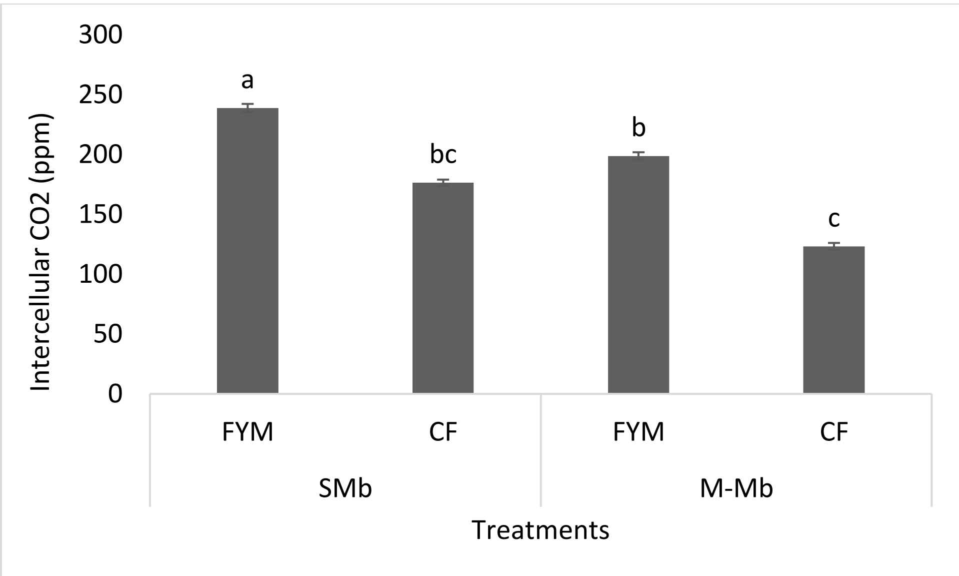

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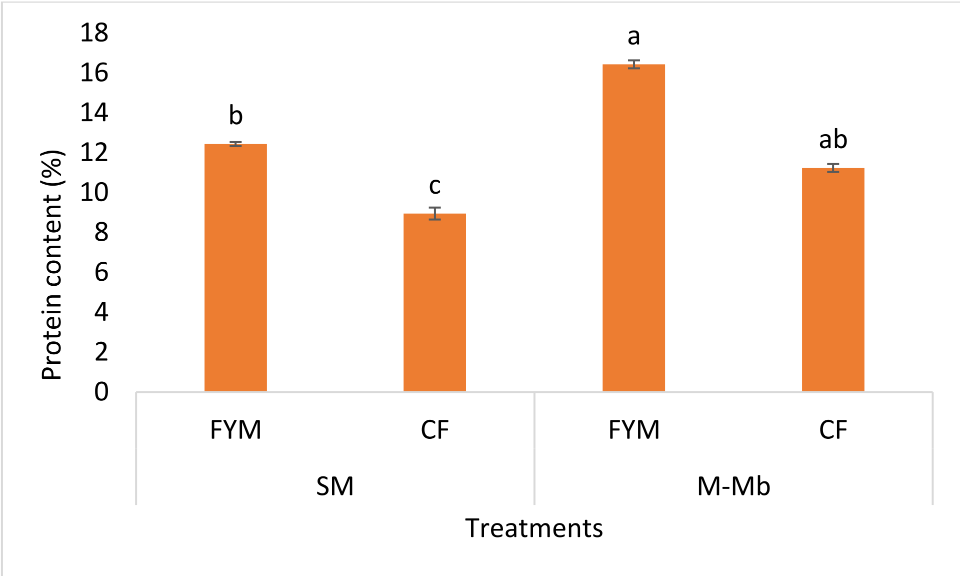
Fig. 4a & 4b. Effect of different cropping practices and nutrient management practices on intercellular CO_2 (ppm) of maize and mungbean, respectively



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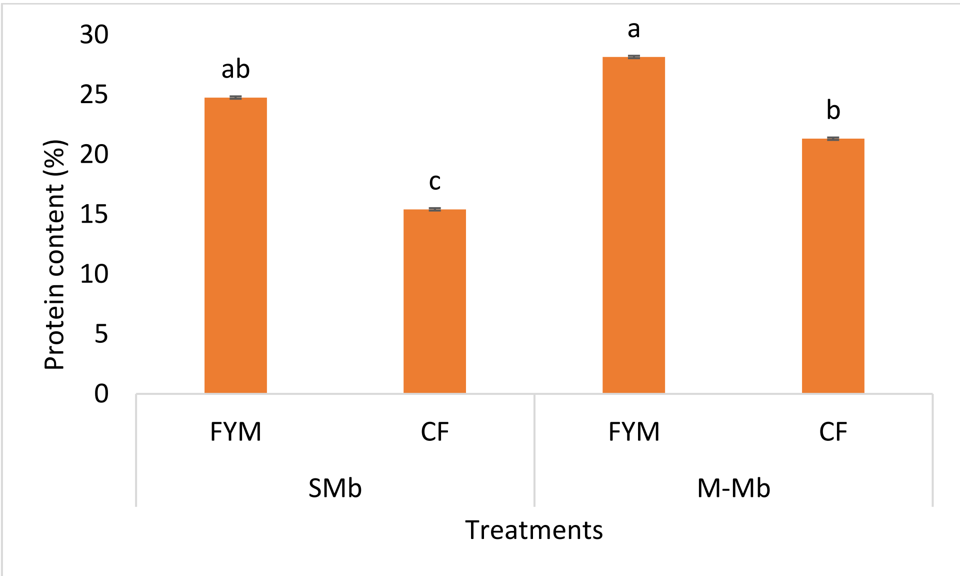

b

Fig. 5a & 5b. Effect of different cropping practices and nutrient management practices on protein content (%) of maize and mungbean, respectively

Mean square values for protein content (%) showed significant variability among both maize and mungbean genotype under the effect of intercropping (Fig. 5a & 5b). The means for various treatments for maize ranged from 8.95 to 16.43 % (Fig. 5a). Maize genotype under maize-mungbean (M-Mb) and vermicompost (VMC) treatments had highest protein content (8.95 %) while lowest protein content (15.78 %) was obtained by sole maize (SM) and chemical fertilizer (CF). On the other hand, the means for various treatments for protein content in mungbean ranged from 15.42 to 28.15 % (Fig. 5b). Maximum protein content (28.15 %) was observed in maize-mungbean (M-Mb) treatment with accrual of vermicompost (VMC) while minimum protein content (15.42 %) was present in sole treatment (SMb) and chemical fertilizer (CF).

Grain yield is an important plant feature because it provides a more accurate evaluation of production by excluding the fluctuations induced by water content. The grain yield of crops is

Table 2. Effect of different cropping and nutrient management practices on the grain yield (kg/ha) of maize and mungbean

CP	Maize		CP	Mungbean	
	NMP			NMP	
	VMC	CF		VMC	CF
SM	8754.1b	7467.4c	SMb	1150.52b	810.27c
M-Mb	8246.1 a	8135.8b	M-Mb	1610.72a	928.38c
SE	18.43		SE	7.5	
CV (%)	6.79		CV (%)	9.23	

Figures in a column having common letters differ significantly at 5% level of significance. SE = Standard error of means; CV (%) = Coefficient of variation; CP = Cropping Practices; NMP = Nutrient Management Practices; SM = Sole Maize; SMb = Sole Mungbean; M-Mb = Intercropped Maize-Mungbean; VMC = Vermicompost ; CF = Chemical Fertilizer

intimately related to plant performance as a result of photosynthetic aptitude, nutrition, environmental conditions, and other variables. The analysis of variance for dry weight (g) showed significant variability among both maize and mungbean mixed by various nutrient management treatments (Table 2). The means for various treatments for maize ranged from 7467.4 to 9246.1 kg/ha (Table 2). Maize under intercropped maize-mungbean (M-Mb) and vermicompost (VMC) treatments displayed maximum grain yield (7467.2 kg/ha) followed by sole maize (SM) treatment with vermicompost (VMC) (8754.1 kg/ha), maximum grain yield (9246.1 kg/ha) was seen in sole maize (SM) and chemical fertilizer (CF) treatments. On the other hand, the means for various treatments for mungbean ranged from 810 .27 to 1610. 71 kg/ha (Table 2). Mungbean genotype under intercropped treatment (M-Mb) and vermicompost (VMC) demonstrated maximum grain yield (1610.71 kg/ha) whereas minimum grain yield (810.27 kg/ha) was produced in sole mungbean (SMb) treatment with application of chemical fertilizer.

3.2 Soil Parameters

Application of nutrient management strategies with the implementation of different cropping practices has meaningfully improved the soil properties and soil fertility as shown in Table 3. SOM content has been significantly altered by the applications of these approaches in all cropping practices, it ranged from 0.14 to 0.78%. Intercropped maize-mungbean (M-Mb) with vermicompost (VMC) has observed highest SOM content (0.78%) while lowest value, 0.22% was in sole maize (SM) of chemical fertilizer (CF) followed by sole mungbean (SMb) of chemical fertilizer (CF) (0.21%) (Table 3). Likewise, the value of available N fluctuated between 0.09 to 2.98 ppm in all the cropping practices and nutrient management practices in this experiment. In sole maize (SM) and chemical fertilizer (CF) treatments, the value of available N has diminished to 0.09, however there was significant increase of available N to 2.98 ppm in intercropped maize-mungbean (M-Mb) by implementing vermicompost (VMC). Also, intercropped maize-mungbean (M-Mb) with chemical fertilizer (CF) has given better and improved results of available N with value of 2.11 ppm (Table 3).

pH in soil was 4.50 to 6.44 by the application of nutrient management and cropping practices. pH decreased to 4.50 in the sole maize (SMb) treatment of vermicompost (VMC) followed by sole maize (SM) of chemical fertilizer (CF) (4.54) while intercropped maize-mungbean (M-Mb) with vermicompost (VMC) increased available P content to 6.44 (Table 3). Available P has been significantly improved by the applications of these management approaches with both cropping practices, it ranged from 5.98 to 18.67 ppm. Maize-mungbean (M-Mb) has observed highest available P, 18.67 along with the addition of vermicompost (VMC) and while lowest value, 5.98 ppm was in sole maize (SM) of chemical fertilizer (CF) followed by sole maize (SM) of vermicompost (VMC) with 7.12 ppm, which were statistically similar to each other (Table 3).

Available K ranged from 121.53 to 198.76 ppm in both vermicompost (VMC) and chemical fertilizer (CF) along with cropping practices, sole maize (SM), sole mungbean (SMb) and intercropped maize-mungbean (M-Mb), showing the highest value (198.76 ppm) in maize-mungbean intercropped treatment (M-Mb) with addition of vermicompost (VMC) in it followed by M-Mb with chemical fertilizer (CF)

Table 3. Effect of different cropping practices and nutrient management practices on the soil properties

CP	pH		EC (dS/m)		CEC (cmol/kg)		Exchangeable Ca (cmol/kg)		Exchangeable Mg (cmol/kg)	
	VMC	**CF**	**VMC**	**CF**	**VMC**	**CF**	**VMC**	**CF**	**VMC**	**CF**
SM	4.54c	4.50d	0.29c	0.21cd	35.60bc	32.42c	4.21c	3.98d	1.19c	1.02c
SMb	5.66b	5.13bc	0.41b	0.24c	39.41ab	38.11b	5.86bc	5.14bc	1.77b	1.54bc
M-Mb	6.44 a	5.96ab	0.51 a	0.33bc	44.31a	41.33ab	6.42a	5.91b	2.21a	1.97ab
SE	0.21		0.14		1.15		0.19		0.16	
CV (%)	1.64		3.72		1.58		0.95		0.73	

CP	SOM Content (%)		Available N (ppm)		Available P (ppm)		Available K (ppm)	
	VMC	**CF**	**VMC**	**CF**	**VMC**	**CF**	**VMC**	**CF**
SM	0.45b	0.14c	0.21c	0.09c	7.12bc	5.98c	156.92cd	121.53d
SMb	0.64ab	0.29bc	1.64bc	1.23bc	15.95ab	10.43b	182.65bc	161.21c
M-Mb	0.78a	0.69ab	2.98a	2.11b	18.67a	17.15ab	198.76°	178.87b
SE	0.05		0.16		0.15		5.63	
CV (%)	0.79		1.99		2.14		1.78	

Figures in a column having common letters differ significantly at 5% level of significance. SE = Standard error of means; CV (%) = Coefficient of variation; CP = Cropping Practices; SM = Sole Maize; SMb = Sole Mungbean; M-Mb = Intercropped Maize-Mungbean; VMC = Vermicompost (VMC); CF = Chemical Fertilizer.

(178.87 ppm). The lowest value 121.53 ppm was observed by sole maize (SM) with amendment chemical fertilizer (CF) (Table 3).

In CEC of the soil there was significant change was observed from 32.41 to 44.31 cmol/kg in both cropping and nutrient management practices in this experiment. In vermicompost (VMC) and intercropped maize-mungbean (M-Mb) treatments, soil CEC increased to 44.31 cmol/kg in contrast to the chemical fertilizer (CF) of intercropped maize-mungbean (M-Mb) having CEC with 41.33 cmol/kg (Table 3). On the other hand, minimum increase (32.41 cmol/kg) was assessed in sole maize (SM) with chemical fertilizer (CF) (Table 3). Exchangeable Ca has been significantly changed by the application of nutrient management strategies with implementing different cropping practices, it ranged from 3.98 to 6.42 cmol/kg in this experiment. Intercropped maize-mungbean (M-Mb) has observed optimal value of exchangeable Ca (6.42 cmol/kg) with implementing of vermicompost (VMC) while lowest value, 3.98 cmol/kg was in sole maize (SM) and chemical fertilizer (CF) (Table 3). Similarly, the exchangeable Mg varied between 1.02 to 2.21 cmol/kg in vermicompost (VMC) and chemical fertilizers (CF) along with sole maize (SM), sole mungbean (SMb) and maize-mungbean (M-Mb) used as cropping practices. In chemical fertilizer (CF) of sole maize (SM), the exchangeable Mg has reduced to 1.02 cmol/kg, however there was significant increase to value of 2.21 cmol/kg in vermicompost (VMC) of maize-mungbean (M-Mb) followed by chemical fertilizer (CF) of intercropped maize-mungbean (M-Mb) with exchangeable Mg of 1.97 cmol/kg (Table 3).

4. DISCUSSION

Nasar et al., [17] performed maize-mungbean intercropping at optimal N fertilization boosts maize crop N absorption, yield, and N usage efficiency through modulating N assimilatory enzymes and recorded similar results for chlorophyll content. Adding to this, Ro et al., [18] led research to check impact of intercropping in maize and mungbean yield and quality parameters and found similar results that mungbean and maize is boosted as intercropping plays its pivot role. Meanwhile, Amanu et al., [19] assessed yield and nutritive value of maize-legume intercropping systems in paddy fields during summer by sowing maize with soybean and obtained same increased intercellular CO_2 as a result of intercropping. The amount of CO_2 raises as nutrient level is maximized to optimum with the intercropping of cereal legume practices [20]. Plant proteins provide a variety of enzymatic, structural, and functional functions. They also serve as storage media to suit the nutritional and development requirements of growing seedlings [21]. Tamta et al., [22] findings on the nutritional profile of mungbean and maize utilizing diverse intercropping ratios and balanced fertilization of nitrogen are consistent with present protein content findings. Moreover, Ibrahim et al., [23] also investigated fodder nutrition of mungbean and maize as solo crops as well as mixtures at different seed ratios and noticed similar results for protein content in both maize and mungbean. Kumari et al., [24] investigated the impacts of intercropping on crop and livestock profitability, health of the soil growth, and insect dynamics in a rainfed region of India and discovered comparable results for grain yield. Similarly, vermicompost (VMC) heightens up the grain yield with intercropped cereal legume practice and this is the result of increased nutrient output to soil and equally provided to plant which is efficiently taken up by both crops [22]. Geren et al., [25] intercropped maize with cowpea to find yield output and quality of grain and reported improvement in grain yield for both crops.

One of the most important and effective cropping practice for improving crop yield and soil is vermicompost [26]. The amount of vermicompost [27] as well as the essential initial chemical and physical properties, such as pH buffering capability and soil organic matter [28], have a significant impact on how vermicompost affect soil pH.

The impact of intercropped cereal legume with vermicompost incorporation appeared to be larger when the initial soil SOM was high because high SOM typically leads in high soil CEC and pH buffer capacity [29]. This is a result of the complex interactions between soil, plants, and the environment as well as the variety of soil's physical and chemical characteristics [27]. This whole changing behavior in the soil leads to the betterment of plant growth and in end result is provided with improved protein content [21]. In accordance with Wangiyana [30], our findings showed that the application of vermicompost with sole maize (SM) and sole mungbean (SMb) elevated the pH by roughly 23.49% and 23.70%, respectively after the experiment, but increased soil acidity by 32.45% in maize mungbean intercropped plot (M-Mb) (Table 3). The addition of VMC in M-Mb treatment could have increased the pH of the soil through any of the following processes or combinations of processes: consumption of proton by functional groups linked to organic materials [31], decarboxylation of organic acid anions during decomposition, specific adsorption of organic molecules by ligand exchange with the release of OH [32], and the release of OH ions during reduction reactions linked to localized anaerobic microsites.

According to prior research by Diatta [33], the application of vermicompost together with the maize-mungbean cropping practice improved the soil's available N, P, and K content due to a rise in soil pH. Because of the maize-mungbean intercropping practice and the use of vermicompost, the availability of exchangeable Ca and Mg increased as soil pH increased, which was also reported by Mosharof et al. [30] and Kunhikrishnan et al. [7]. According to Lyngdoh et al. [34] and Amanullah et al. [35], increasing soil pH due to vermicompost amendment with maize-mungbean intercropped treatment also raised soil EC and CEC. The M-Mb cropping practice is best suited for areas where weed growth is intense [36] because it enhanced the soil's characteristics by making more nitrogen available and bringing the pH level closer to that of growth [37]. This also improves the plant photosynthetic rate which leads to the improvement of respiration [31].

The efficiency of nutrient usage can also be influenced by management techniques [34] in addition to the transformation and uptake of nutrients by plants [12, 38]. It is generally acknowledged that cereal legume intercropping can deliver basic cations like Ca and Mg to the root zones while also neutralizing excess acidic ions in the soil like proton ions and other acidic mineral cations (like Al ion) [39].

According to Ajio et al. [40], raising the pH of the soil boosted soil microbial activity and had a significant impact on the rate of soil C and N cycling. The optimal P nutrition for arable crops depends on the connection between soil pH and P availability [41]. The ideal soil pH for P absorption needs to be reevaluated, according to Frida et al. [42]. However, organic matter concentration significantly affects yield response to P and should be taken into account in addition to pH [43]. Recent studies in Ethiopia and Germany, Wang et al. [44] and von Nasar et al. [45], have shown the influence of P status on yield response to pH for barley especially where it was intercropped with legume.

5. CONCLUSION

In conclusion, the study suggests that intercropping maize and mungbean, particularly when combined with vermicompost, can lead to improved plant parameters; chlorophyll content, photosynthesis rate, protein content, and grain yield and positively influence soil parameters; SOM, nutrient availability, pH, CEC, and exchangeable Ca and Mg. These findings are consistent with existing research on the benefits of intercropping and the use of organic amendments like vermicompost to enhance crop productivity and soil fertility.

The use of vermicompost in intercropped systems appears to have multiple benefits, including improved soil fertility, better nutrient availability, and increased plant performance. The higher chlorophyll content and photosynthesis rate in intercropped treatments suggest that this approach can enhance the photosynthetic capacity of the plants, which is crucial for crop growth and yield. Additionally, the increased protein content in crops is beneficial for both livestock feed and human nutrition.

Overall, the study supports the idea that intercropping, in combination with appropriate nutrient management practices, can be an effective strategy for maximizing agricultural productivity and improving soil health. It is also important to note that soil parameters, such as pH, SOM, and nutrient availability, play a crucial role in crop performance, and proper management of these factors can lead to significant benefits for farmers and the environment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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